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A CUSTOM DESIGNED EMI FILTER FOR COMPUMOTOR STEPPING MOTORS

Report No. 90-277-K
D.W. Donnelly
Advanced Systems Technology Section
Metallurgical Research Department

ABSTRACT

The Nondestructive Evaluation Unit in the Metallurgical Research Department has built several automated scanning rigs driven by high resolution stepping motors manufactured by Parker-Compumotor. For several years, we have been attempting to solve the problem of Compumotor generated electrical noise invading the inspection instrumentation attached to these rigs and interfering with data collection. This report describes a motor filter that was designed and constructed by an external company which effectively eliminates the noise problem in most practical inspection situations.

job	file	date	report no.
83-551-051	826.1	January 8, 1991	90-277-K

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EXECUTIVE SUMMARY

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D.W. Donnelly
Advanced Systems Technology Section
Metallurgical Research Department

The Nondestructive Evaluation Unit in the Metallurgical Research Department has built several automated scanning rigs driven by high resolution stepping motors manufactured by Parker-Compumotor. These motors provide positioning accuracy far greater than that offered by conventional stepping motors; however, they emit a significant quantity of electrical noise. For several years, we have been attempting to solve the problem of Compumotor generated electrical noise invading the inspection instrumentation attached to our scanning rigs and interfering with data collection. We consulted Parker-Compumotor and called upon local experts for advice. Despite all of our efforts and some significant reductions, this noise remained a serious nuisance and has periodically become a limiting factor in the data collection process.

An external company specializing in electronic design and fabrication was asked to assess the problem and make recommendations. They suggested that a motor filter be designed and installed to reduce the noise at its source to a level where it would no longer be a detrimental factor during data collection. Hydro contracted this company, CSI Electronics, to build and install the filter which, when complete, produced very impressive results. With the filter installed, motor generated noise is below general background noise levels in almost all scanning situations. We, therefore, intend to purchase additional filters and install them on all of the laboratory scanning rigs that are used in conjunction with sensitive inspection instrumentation.

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TO: D. Mills
Director of Research

A CUSTOM DESIGNED EMI FILTER FOR COMPUMOTOR STEPPING MOTORS

INTRODUCTION

Several years ago, we in the Nondestructive Evaluation Unit in Ontario Hydro's Metallurgical Research Department decided to construct a series of high resolution laboratory scanning systems to supplement and eventually replace existing scanning rigs that were up to ten years old. Intended primarily for ultrasonic and eddy current inspection procedures, we decided that these new systems would require positional accuracy of one micron for linear motion and one-thousandth of a degree for rotary motion. We selected stepping motors for the drive systems due to their stability and ease of control, even in open-loop configurations.

Conventional stepping motors have positional resolutions of approximately 1.8 degrees. To obtain one thousandth of a degree, reduction gearing by a factor of 1800 would be required. This complicates the mechanical design, adds great potential for backlash in the gear box, and results in a system that has no high speed capabilities. Such a system would be unacceptable, but fortunately, after some searching, we found a company in the United States that produces a high resolution stepping motor system. This company, called Parker-Compumotor, offers a series of motors and control systems with a positional resolution of 0.028 degrees and the ability to operate over a wide range of motor velocities. These capabilities greatly reduced the complexity of the mechanical design and allowed us to construct several scanning systems that met all of our requirements.

The Parker-Compumotor stepping motor system achieves high positional resolution through a Pulse Width Modulation (PWM) drive scheme. In this scheme, current to the various phases of the stepping motor is switched on and off in rapid succession to hold the motor's rotor in different locations between its natural poles. The switching frequency is approximately 20 kHz, which is not a problem in itself, but an electrical noise problem is created by the high frequency components of the sharp rising and falling edges generated by the switching on and off of the current. This high frequency noise invades the sensitive ultrasonic inspection equipment attached to the scanning rig and often creates a background noise level high enough to completely mask the UT signals of interest.

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Over the past two years, we have invested a great deal of time and effort in an attempt to reduce the stepping motor noise problem to an acceptable level. We have had varying levels of success on different scanning rigs and have generally managed to reduce the noise sufficiently to complete the work at hand. There have been many occasions, however, where inspection sensitivity was sacrificed or many hours were spent taking extraordinary measures to obtain reasonable ultrasonic inspections. After consulting Parker-Compumotor and in-house electronics experts, we significantly modified some of our scanning rigs, but the results were not satisfactory. Despite the fact that we exhausted all known avenues related to the shielding and grounding of the motor and UT inspection systems, electrical noise persisted as a serious and regular obstacle to ultrasonic inspection.

Ten years ago, most ultrasonic instruments operated in the one to twenty MHz range. Today, more work is being done in the twenty to one hundred MHz range and this trend appears to be increasing. At these higher frequencies, we found that electrical noise generated by the stepping motors became a limiting factor. Something had to be done. After consulting with Parker-Compumotor again, we decided to employ a consultant specializing in electrical design to assess the problem and to design a filter that would essentially eliminate the noise at its source. CSI Electronics was called in and approximately three months after the initial contact, they delivered the filter described in this report.

EMITTERS AND RECEIVERS

A simple, one-dimensional scanning rig is illustrated in Figure 1. It utilizes a computer to control the operation of the system and to collect and process data. The computer is connected to the Compumotor stepping motor drive via an RS-232 serial communications cable, which it uses to send commands to the drive and to read back status. The drive provides both the power and the logic required to step the motor. It is connected to a standard AC outlet and to the motor itself. The computer is also connected to an ultrasonic instrument via an analogue or digital cable depending on the instrument and type of scan being performed. Finally, a coaxial cable links the UT instrument to an ultrasonic transducer mounted on the scanning rig.

The source of the electrical noise picked up by the UT instrument is clearly the Compumotor drive, but the noise path is not so clear. After much investigation, we found the following sources of noise emission from the drive system:

1) The Compumotor drive itself emits significant quantities of EMI into the environment, even when its metal enclosure is grounded;

2) The AC power cable connecting the drive to the mains acts like a transmitting antenna for the drive;

3) The serial communications cable connecting the drive to the computer acts like a transmitting antenna;

4) The motor emits some EMI into the environment and provides a conductive path between the scanning rig and the drive through the motor cable shield; and

5) The cable connecting the motor to the drive emits like an antenna.

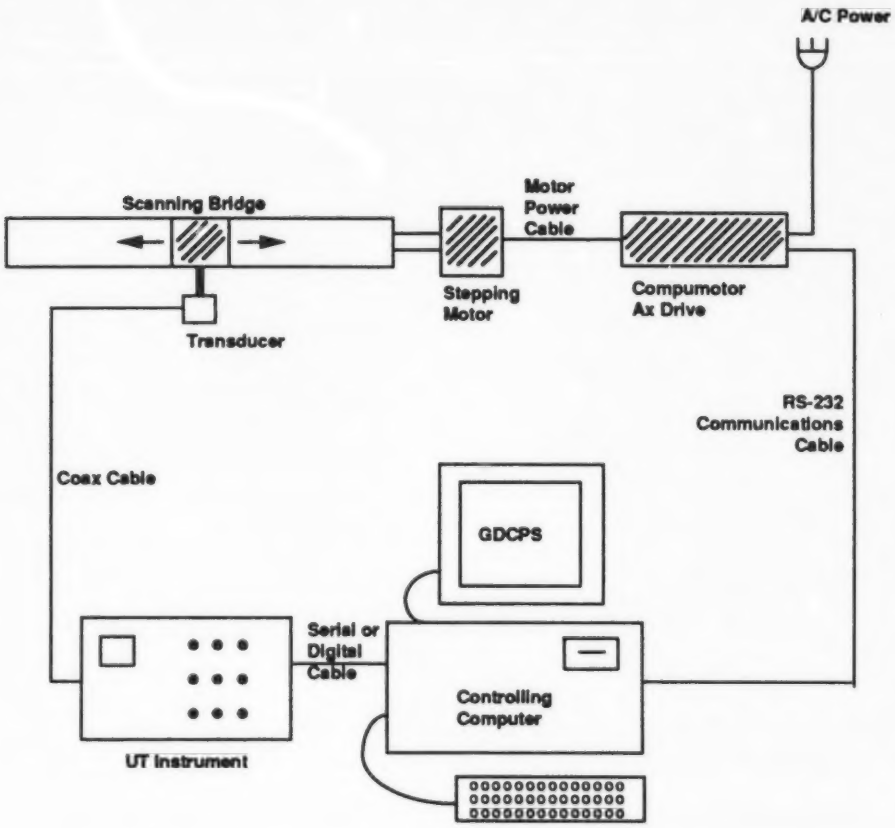

FIGURE 1: A Simple One-Dimensional Scanning Rig

Having identified the paths by which noise entered the ultrasonic inspection environment, we then attempted to isolate the paths by which this noise entered the UT instrument itself. We found the following:

1) The major source of noise infiltration was through the coaxial cable connecting the UT instrument to the transducer;

2) Under some circumstances, noise was picked up by the metal shell of the transducer when it was placed in physical (ie. conductive) contact with the scanning rig; and

3) Some noise entered the UT instrument through its AC power cable.

The relative importance of the various emitting and receiving paths was difficult to quantify and varied from one scanning rig to another. It even seemed to vary from one day to another which was most likely the result of weather changes, inadvertent minor changes in the experimental set-up, and circumstances in the local environment that were beyond our control.

INITIAL ATTEMPTS TO ELIMINATE THE NOISE PROBLEM

After discovering the major paths for noise transmission and reception, a number of efforts were made to block these paths. Selections from the following list of remedies were applied in various combinations to different scanning rigs with varying levels of success:

1) The AC power line cables connecting the Compumotor drives to the mains were replaced with shielded AC cables;

2) In-line AC power filters were installed between the drives and the mains to reduce the quantity of noise entering the mains;

3) The drives were securely grounded to the AC power line filters, the scanning rig, the computer, and the UT instrument;

4) The cables connecting the drives to the motors were shortened as much as possible and the shields were checked for proper connections. Extra shields were sometimes installed over the motor cables;

5) Non-metallic connectors were replaced with grounded metallic connectors wherever possible;

6) Power cables were routed away from signal cables as much as possible; and

7) Extra shielding was applied over the coaxial cable connecting the transducer to the UT instrument.

Unfortunately, the Compumotor drives are such powerful noise emitters and the UT instruments are such sensitive receivers, that despite all of our efforts, we could not bring the noise down to acceptable levels in all circumstances. Thus, another alternative had to be explored; this turned out to be a motor filter.

DESIGNING THE MOTOR FILTER

After deciding to investigate a motor filtering system, we first contacted Parker-Compumotor to see if they currently had a commercially available unit or if they had any interest in designing one. In response to our inquiry, they sent us a prototype filter board that was the result of some earlier discontinued work. This filter had minimal impact on noise and eventually caused one of our drives to fail because the filter's inductance was too low. At this point, we decided to pursue the acquisition of a filter through another company.

Representatives from CSI Electronics came to our laboratory and spent one day analyzing the field situation and assessing the Parker-Compumotor drives. They also took one pair of drives back to their office for further experimentation. Approximately four months later, CSI delivered a complete filter and began the in-field testing phase.

Initial results were somewhat discouraging as the filter appeared to give only a six decibel improvement in the signal to noise ratio. Several problems were quickly located and CSI took the filter back to their office for modification. A week or so later, the filter was brought to our location again and installed. Due consideration was given to the grounding of the entire scanning rig and associated inspection equipment and the filter performed much better. In most situations, it became impossible to separate the noise generated by the motor drives from the general background noise level. A more detailed analysis of the filter's performance is given in the section of this report titled Filter Performance. A technical description of the filter is provided in Appendix A.

FILTER PERFORMANCE

To obtain an accurate measure of the effectiveness of the filters, several measurements were made with ultrasonic transducers designed to operate in different frequency ranges. The UT instrument used for the tests was a Krautkramer Branson KB6000 connected to a twelve inch long metal search tube with a transducer on the end. This search tube was mounted in a two-dimensional scanning rig driven by two Compumotors. The search tube was in electrical contact with the rig as this appeared to give improved noise immunity.

Measurements were made with ultrasonic transducers having central operating frequencies of 10, 15, 25, and 50 MHz. For each transducer, readings were taken with the Compumotor drives off, with the drives on and no filter installed, and with the drives on with the filter installed. Each reading was obtained by increasing the gain of the UT instrument until the total noise level (background and motor generated) reached an amplitude of thirty percent full screen height on the instrument's video display. This simulates a maximum scanning gain in a hypothetical inspection situation. These gain readings are plotted against transducer frequency in Figure 2.

The plots in Figure 2 show that for all but the 50 MHz probe, no scanning gain was lost due to Compumotor generated noise while the filter was installed. In some cases, the full performance of the filter cannot be measured until the background noise level is reduced. The 50 MHz probe is particularly sensitive to motor noise and we lose 3 dB of scanning gain when the filtered motor drives are operating. This is not too surprising when one considers that the unfiltered drives decrease scanning gain by 22 dB. For the other three transducers, the unfiltered drives decrease scanning gain by approximately 13 dB.

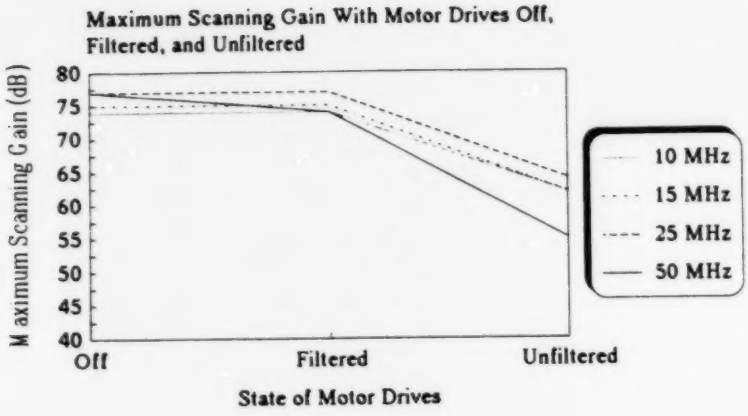

FIGURE 2: Maximum Scanning Gain Versus Motor State Without Slip-Ring

Figure 3 shows the results of a similar test performed on the same scanning rig, but with the UT signal line passing through a slip-ring before reaching the KB6000. Slip-rings are notorious for noise emission, pick-up, and cross-talk. With the filter installed during this test, scanning gain is down by approximately sixteen dB from the case where the motors are disconnected. There is, however, an improvement of approximately fifteen dB over the case where the motors are unfiltered. Fortunately, slip-rings are not usually essential in laboratory two-dimensional scanning rigs. In cases where they must be used, it is advisable to amplify the UT signal before it enters the slip-ring.

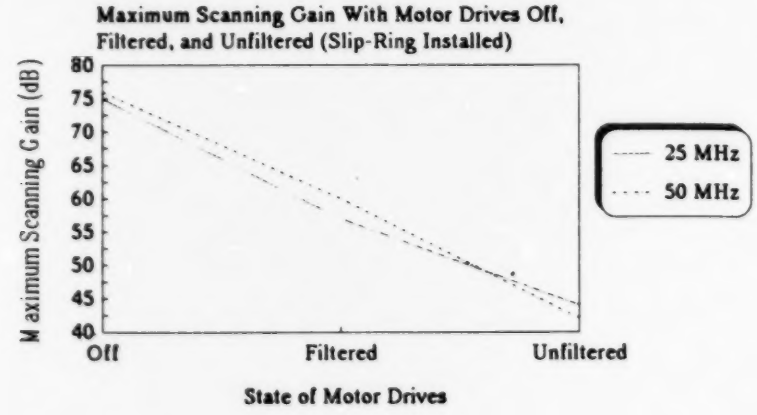

FIGURE 3: Maximum Scanning Gain Versus Motor State With Slip-Ring

Although Compumotors come in a wide variety of sizes with differing drive current requirements, it was possible to design one filter that was compatible and effective with the entire range of motors and both the high and low current versions of the Compumotor AX style drives. The installation of the filter does cause a small loss of torque at high motor speeds, but this loss is considered negligible.

Because the motor provides an inductive load to the Compumotor drive, disconnecting it from the drive while the motor is energized often causes the drive to fail in a manner that requires factory servicing. When installed, the filter acts as a buffer between the drive and motor, making it possible to safely disconnect the motor, even when energized.

PACKAGING AND ECONOMIC CONSIDERATIONS

Since most scanning rigs require two or more motors to be driven simultaneously, CSI has packaged two filters into a rack mountable enclosure that also houses two Compumotor drives. This allows filtering of all drive inputs and outputs, provides shielding for the drives and internal wiring, provides cooling through a self-contained fan, and provides convenient shielded connection points for all relevant inputs and outputs.

For the job of assessing the Compumotor noise problem, designing and constructing a dual drive filter unit, field testing, modifying, and installing one complete unit, CSI Electronics billed Ontario Hydro approximately $10,000. Additional filter units, each capable of servicing two drives, are available at a cost of approximately $2,000 per unit.

CONCLUSIONS

The Compumotor filter unit designed and built for Ontario Hydro by CSI Electronics has essentially cured the problem of Compumotor generated electrical noise invading our nondestructive inspection systems. In most situations, the level of motor generated noise picked up by the inspection instrumentation is equal to or less than general background noise levels in the laboratory. The filter unit is compact, easily installed, and provides protection for the motor drives which, without the filter in place, could be seriously damaged by disconnecting the motors from the drives while energized.

The installation of the CSI filter in the Compumotor drive-motor loop may result in a small loss of torque at high motor speeds. This disadvantage is more than offset by the decrease in emitted electrical noise; therefore, the installation of these filters in all of the NDE lab inspection rigs connected to sensitive instrumentation is highly recommended.

Recommended by:

Michael Moles

M.D.C. Moles
Acting Section Head
Advanced Systems Technology

Prepared by:

D W Donnelly

D.W. Donnelly
Engineer
Advanced Systems Technology

Approved by:

James Brown

J. Brown
Manager
Metallurgical Research Dept

DWD:SEHG

APPENDIX A

Technical Description of CSI Filter (Supplied by CSI Electronics)

Product: Motor Drive Filtering System

Introduction:

The Motor Drive Filtering System developed by CSI Electronics will conveniently enclose up to 2 Compumotor AX Series Drive/Indexer systems. Filtering is provided for motor outputs, power line inputs and RS-232 communications. Instrumentation systems which are sensitive to the noise generated by pulse width modulated motor drives can benefit greatly by having the motor drives mounted in this filtering system. Built-in cooling fan, convenient signal connections, and motor drive short circuit protection are additional benefits provided by this integrated system.

System Features:

The rack-mountable chassis neatly houses two AXL or AXH Compumotor drives.

Forced-air cooling makes Compumotor manufactured fan kits unnecessary.

Motor connections are made using circular mil connectors.

Encoder and indexer connections are made using D-subminiature connectors.

The filter is rated to drive all motors in the AXL and AXH range (size 23,34 and 42).

The correct inductive load is always presented to the motor drives thus protecting the drives in the case of a short circuit in the motor wiring.

The fused power entry system provides convenient circuit protection.

Filter Description:

The Motor Drive Filtering System incorporates floating dual fourth order balanced Pi filter networks. These filters remove the high frequency switching transients from the AX drive's 20 kHz pulse-width modulated amplifiers.

The filter was designed to have a very high Q over a very wide band of frequencies. The overlapping frequency bands of the filters provide a minimum of 40 dB attenuation from several kilohertz well into the UHF band.

On the power entry side, extensive line filtering is provided which keeps RFI from radiating from the power cord and from entering the power distribution network.

The RS-232 lines are filtered using T filters on the RX and TX lines.

The current rating of the filter system is 6 Amps continuous so that all motors supported by the AX series of motor drives can be used.

Specifications:

Width:	19" rack mount
Height:	7" (4U)
Depth:	18.7"
Weight:	50 lb. (22.7 kg)
Max Current:	6 A continuous per phase
Line Fuse:	10 A